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For the Communications Systems Network Interoperability (CSNI) project two different protocols were implemented for the SATCOM subnetworks. The United Kingdom developed a TDMA/Token Ring protocol for SHF SATCOM subnetwork, and the United States developed a Reservation Protocol for UHF SATCOM subnetwork. The U.K. provided two versions of their protocol. One version supports a multiple member subnetwork and is used with the WESTLANT DSCS satellite. Canada, Shape Technical Centre (STC), U.K., and the U.S. formed the members of this subnetwork. The link data rate for this subnetwork is 56 kbps. The second version supports a point-to-point connection and is used with the NATO IV satellite. There are three SHF point-to-point links: STC-Netherlands, STC-Germany, and U.K.-Germany. All the point-to-point links support a link data rate of 64 kbps.

There are two UHF SATCOM subnetworks. Both use the same reservation protocol. One subnetwork uses the FLTSAT7 satellite and consists of three nodes: Canada, U.S. at NRaD, and U.S. at NRL. The second subnetwork uses the FLTSAT1 or 8 satellite and consists of five nodes: Canada, three nodes in the U.K., and the U.S. at NRL. The link data rate for both subnetworks is 9.6 kbps.

All the designs adhere to the CSNI SNAC External Interface Specification which allows any CSNI subnetwork to attach to any participating CSNI intermediate system. This paper discusses the protocols and how the software is implemented. A discussion of over the air test results is also provided.

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SATCOM SUB NETWORK

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ABSTRACT

For the Communication Systems Network Interoperability (CSNI) project two different protocols were implemented for the SATCOM subnetworks. The United Kingdom developed a TDMA/Token Ring protocol for SHF SATCOM subnetwork and the United States developed a Reservation Protocol for UHF SATCOM subnetwork. The U.K. provided two versions of their protocol. One version supports a multiple member subnetwork and is used with the WESTLANT DSCS satellite. Canada, Shape Technical Centre (STC), U.K. and the U.S. formed the members of this subnetwork. The link data rate for this subnetwork is 56 kbps. The second version supports a point to point connection and is used with the NATO IV satellite. There are three SHF point to point links: STC-Netherlands, STC-Germany and U.K.-Germany. All the point to point links support a link data rate of 64 kbps.

There are two UHF SATCOM subnetworks. Both use the same reservation protocol. One subnetwork uses the FLTSAT7 satellite and consists of three nodes: Canada, U.S. at NRaD and U.S. at NRL. The second subnetwork uses the FLTSAT1 or 8 satellite and consists five nodes: Canada, three nodes in the U.K. and the U.S. at NRL. The link data rate for both subnetworks is 9.6 kbps.

All the designs adhere to the CSNI SNAC External Interface Specification which allows any CSNI subnetwork to attach to any participating CSNI intermediate system. This paper discusses the protocols and how the software is implemented. A discuss of the over the air test results is also provided.

1.0 INTRODUCTION

Two SATCOM subnetworks were developed for CSNI: SHF and UHF. Figures 1 and 2 show the topology of the two subnetworks. The SHF SATCOM subnetwork consists of one 4 member subnetwork and three point to point links. The subnetwork uses the U.S.'s Defense Satellite Communications System (DSCS) Phase III satellite located at 53 degrees west. The point to point links use individual 64 kbps channels on the North Atlantic Treaty Organization (NATO) IV satellite. The U.K. developed a TDMA/token ring protocol for the DSCS subnetwork. The protocol was modified to work for the point to point NATO IV links.

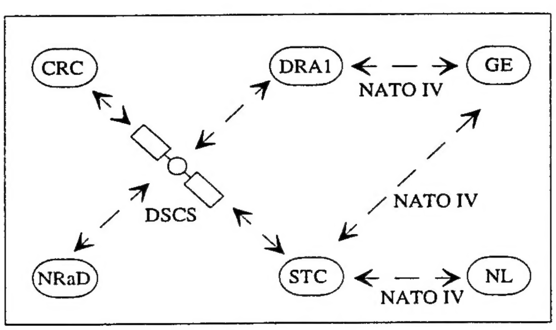

Figure 1. SHF SATCOM Subnetwork

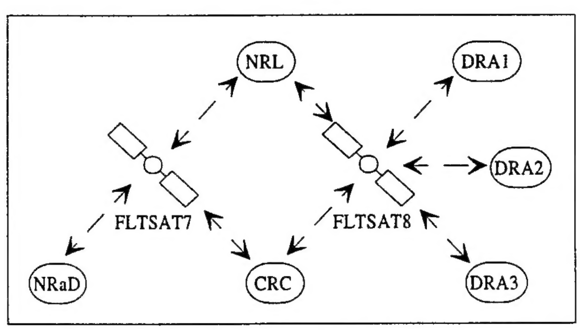

Figure 2. UHF SATCOM Subnetwork

The UHF SATCOM subnetwork actually consists of two subnetworks. One subnet uses the U.S.'s FLTSAT7 satellite. This satellite is located at 100 degrees west and is only visible to nodes in North America. The second subnetwork uses FLTSAT8 which is located at 23 degrees west and occasionally FLTSAT1 (15 degrees west). These two satellites are visible to the nodes on the east coast of North America and Europe. The protocol used on both UHF subnets is a reservation protocol. The protocol was developed by the U.S. on a previous program and adapted to UHF SATCOM.

2.0 SHF SATCOM

2.1 Protocol Description

2.1.1 DSCS

This subnet is a "broadcast" network. The protocol is based on TDMA, but with the slots allocated on a "token passing" basis. The following is a summary of the protocol, for more detail see refs. [1] and [2]. The protocol allows a number of stations (maximum 64, but more than twenty would probably be impractical) to share a single 112 kbps satellite channel (the user date rate is 56 kbps), by time-division multiplexing. There is no master station, and therefore no single ground-based point of vulnerability.

The protocol is based on a frame length of 0.7 seconds, this is divided into ten individually allocated time slots. The tenth slot in every frame cannot be owned by any of the subnet members, it is designated the "empty slot" and is used by nodes wishing to join the subnet. The protocol uses a system of tokens to share the available slots among the stations. There is one token for each slot in the frame which is available for data transfer (there are nine slots available for data transfer). The system allows stations to take varying proportions of the bandwidth. Each subnet member is passed token(s) in turn, the member with the slot token transmits in that slot in the current frame and passes the slot onto the next member.

Figure 3 shows the frame and slot structure used by the DSCS protocol (with n=10), the Data part of the slot is 420 bytes long and contains a Subnetwork Protocol Data Unit (SnPDU), Figure 4 shows the format of an SnPDU.

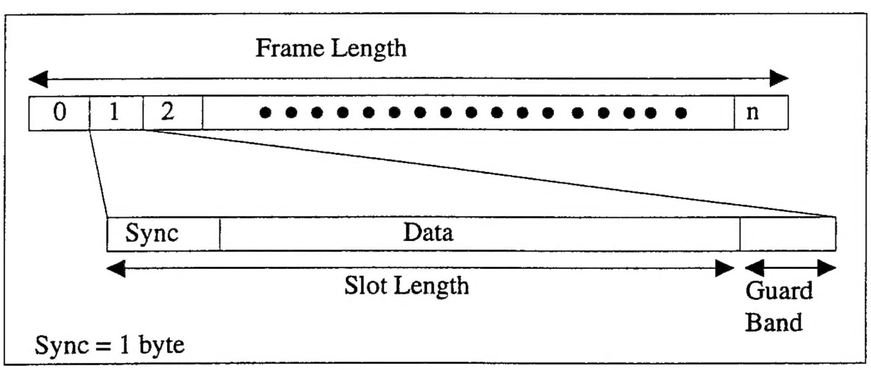

Figure 3. SHF SATCOM Protocol - Frame & Slot Structure

Each slot contains a SnPDU . Each SnPDU can contain one or more NPDUs/NPDU segments (or a mix of both whole NPDUs and segments). All correctly received Data NPDUs/NPDU segments are acknowledged. The recipient Subnetwork Access Control (SNAC) should transmit an acknowledgment to the originating SNAC in the next slot available to him. If an acknowledgment is not received by the station who transmitted the NPDU within N

seconds, then the NPDU is retransmitted, (retransmission will occur R times, after which the NPDU will be discarded and the appropriate action taken).

Token Handling Group (six bytes)
Acknowledgement Group (variable length)
NPDU Descriptor Group (variable length)
NPDU Group (variable length)

Figure 4. Structure of SnPDU

The protocol supports the CSNI group addressing scheme as described in ref. [3].

A transmit queuing capability is maintained by the SNAC. The data sent by the IS is queued on a first-in/first-out (FIFO) basis per priority level. Data is selected for transmission on the basis of highest priority first.

Received data is examined and routed to the destination IS. Any data within the received SnPDU that is not directed to the local IS is discarded.

The DSCS protocol provides the functionality required to reserve fixed rate "channels" at 2.4 kbps, this can be used to support the CSNI Real Time Voice (RTV) Protocol. In the RTV protocol a slot is reserved for a voice call and the slot is passed between the two "ends" of the call by PTT_ON/PTT_OFF signaling.

The channel capacity is 56 kbps, after taking into account headers and guard times the overall data capacity of the subnet is approximately 41.5 kbps. The DSCS subnet has only four users at present, therefore each user has around 10 kbps of data capacity.

2.1.2 NATO

The protocol for this subnet is based on the DSCS protocol. The following is a summary of the protocol, for more detail please see refs. [1] and [4]. The basic frame length (0.7 seconds) and slot structure (420 bytes) of the DSCS protocol has be retained, but each PO owns all the slots for their part of the link, (e.g. UK will have 13 slots/frame to pass information to GE, and GE will have 13 slots/frame to pass information to the UK). The increase in slots over the DSCS Protocol is due to the higher data rate of the NATO IV subnet. The user data rate of this subnet will be 64 kbps.

Figure 3 shows the frame and slot structure used by the DSCS protocol (with n=13). As with the DSCS Protocol, each slot contains an SnPDU (Figure 4). The acknowledgment procedure differs from the DSCS Protocol in that the recipient station does not have to wait for a slot to be handed to him (he owns all 13 slots) before he sends an acknowledgment. The slot structure is not required for point-to-point operation, but was retained for simplicity of implementation (being as it is based on the DSCS protocol).

The utilization of the slots within NATO is identical to that for DSCS (described in 2.1.1 above).

The NATO protocol provides the "channel" reservation required the support the CSNI Real Time Voice (RTV) Protocol. In the NATO subnetwork a slot is reserved in each direction for a voice call, the NATO protocol consisting of full duplex point-to-point links.

The channel capacity is 64 kbps, after taking into account headers and guard times the overall data capacity of the subnet is approximately 53.6 kbps. Because this subnet consists of three separate full duplex links each member of the NATO IV subnet has the 53.6 kbps capacity per link available for him alone to use.

2.2 Software Implementation

All the software for both SHF SATCOM subnets was written in C using the VxWorks development environment. The code was implemented to run on a 68040 based VME processor card and a 68020 based VME serial I/O card.

The software breaks downs into a number of separate, but interconnected, component parts. This break down is the same for both subnets, since the NATO software is based on the code written for the DSCS subnetwork.

The major software components are the Client Handler, this component provides the interface to the CSNI Intermediate System (IS), it has been designed to be conformant with the SNAC External Interface Specification, ref. [2]. The Subnet Protocol, this modules handles all the processing required for transmitting and receiving SnPDUs, including the generation of Acknowledgments and Retransmissions. The Modem Device Driver provides the software interface to the modem/terminal equipment (this software component runs on the VCOM-24 card).

2.3 Hardware Implementation

The Client Handler and the Subnet Protocol are executed on a VME card, the Heurikon HK68V4F processor card. The HK68V4F interfaces to the IS via Ethernet. The output from the Heurikon card is passed to the VCOM-24 card, where it is processed by the Modem Device Driver and sent to the Modem. The VCOM-24 card also provides the serial data link to the Modem (the type of interface was a local issue, dependent on modem/terminal hardware used).

Figure 5 shows the hardware required for each SHF SATCOM subnetwork. The Intermediate System (IS) is the Multinet Controller (which includes the router).

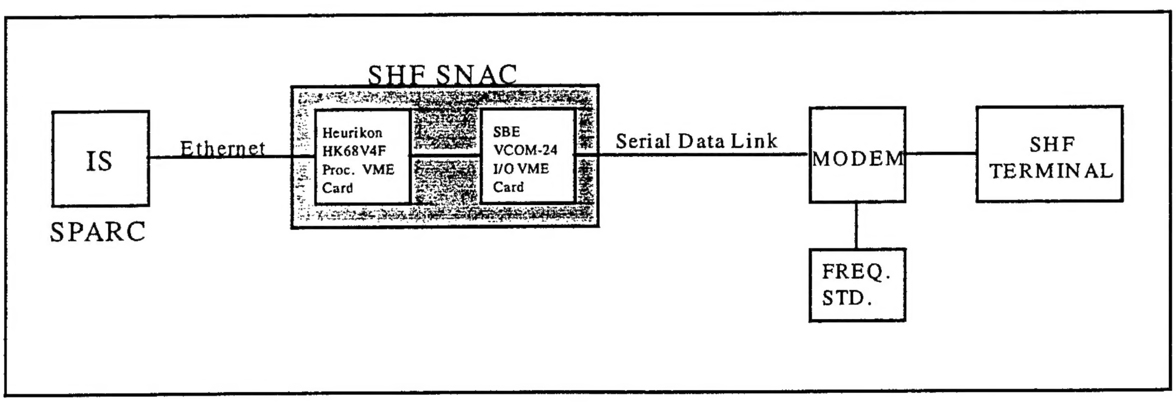

Figure 5. SHF SATCOM Hardware Configuration

The DSCS subnetwork uses the commercially available ComStream CP101 PSK Burst Modem. The NATO subnetwork utilizes NATO SATCOM modem/terminal equipment for the GE-UK and GE-STC links, and commercial IBS/IDR modems for the NL-STC link.

2.4 Test Results

The following two subsections provide a summary of the basic performance characteristics of the two SHF SATCOM subnetworks. The message submission rate for all the tests was one per second.

2.4.1 Summary for DSCS

The DSCS tests were carried out with two members joined to the subnetwork (STC and UK). Table 1 summarizes the results for the four test NPDU sizes.

Test NPDU Size (bytes)	Average Transmission Delay (milliseconds)	Bytes Transmitted	Bytes Retransmitted	Bytes Dropped
100	889	2815	10	0
400	1032	11345	145	0
800	1070	23200	560	0
1400	1410	39282	588	0

Table 1. Summary of DSCS Results

2.4.2 Summary for NATO IV

The NATO tests were carried out over the GE-UK Point-to-Point link. Table 2 summarizes the results for the four different test NPDU sizes.

Test NPDU Size (bytes)	Average Transmission Delay (milliseconds)	Bytes Transmitted	Bytes Retransmitted	Bytes Dropped
100	565	2931	108	0
400	566	11711	411	0
800	644	23446	769	0
1400	786	41038	938	0

Table 2. Summary of NATO Results

2.5 Lessons Learned

2.5.1 Improve DSCS Frame Structure

The DSCS frame structure seems to be inefficient since it never uses all the slots in a frame. The empty slot appears in every frame, however it is only ever used when a PO wishes to join the DSCS subnet. Since POs join the DSCS subnet infrequently it appears to be inefficient to provide an empty slot in every frame.

The best solution would be to include an empty slot in every 'N' frames rather than every frame. This would improve the throughput offered by DSCS, but retain the same basic join methods. Joining would take longer, but since joining is a rare event this should not be overly inconvenient.

2.5.2 DSCS Token Passing Algorithm

The token passing algorithm currently employed by DSCS is very simplistic; the token is always passed to the next PO in the DSCS subnet. The algorithm needs to be made sensitive to the traffic load present at each DSCS SNAC active in the subnet. This would improve transfer times and increase the efficiency of the link.

The token passing algorithm should be further investigated (i.e. to see which is the best). Currently the token is passed irrespective of how much remaining data a SNAC has to transmit.

2.5.3 Satellite Emulation

Testing of the performance of the DSCS/NATO subnet protocols and modem interface software could have been more thorough had it been possible to emulate the satellite link in a controlled manner. In this way it would have been possible to recreate scenarios that caused problems, thus aiding the investigation of the problem and determining of a solution.

2.5.4 Design of TDMA modems

With DSCS it has been noticed that power levels from each site must be balanced because the modem has a slow acting Automatic Gain Control (AGC) circuit which causes problems when the signal level changes, as it may from slot to slot (member to member).

When implementing modems for TDMA applications the AGC circuit must be designed to be fast acting because the signal level may change in each slot. If the power level at each site differs significantly (which could be the case if mobile equipment is used) it can take a significant (compared to the number of sync bits) amount of time to adjust causing data to be lost.

3.0 UHF SATCOM

3.1 Protocol Description

The UHF SATCOM subnet is a broadcast network which uses a reservation protocol [5]. The protocol supports a maximum of 64 members in the network. The cycle time is variable because the channel allocation to each member is dependent on their request. A Net Control Station (NCS) arbitrates the requests and the determines the allocation for each member. The maximum allocation a member can receive per cycle is 9000 bytes. The raw data rate over the UHF SATCOM channel is 9.6 Kbps. The effective data rate of the channel is about 800 bytes per second.

The protocol is designed to fairly and efficiently use the satellite channel with resource allocation based on user demand. The protocol consists of a series of net cycles, each of which is initiated by a NCS. The net cycle is composed of a series of Transmission Units (TUs), one from each transmitting net member. A TU consists of certain fixed-length header fields plus zero or more variable-length messages containing either NPDUs or link control information. The header format is shown in figure 6. A reliable subnet is provided by having each receiving SNAC broadcast an acknowledgment for each PDU indicating whether it was received correctly or not.

There is one NCS per subnet, although other stations can be capable of assuming the role of NCS in the event of failure of the primary NCS. To initiate each net cycle, the NCS transmits a TU which contains a Sequence Order List (SOL). The SOL will contain a list of stations which gives each node a transmit opportunity during the given net cycle, a list of recognized net members which will not transmit during this cycle (if any) and the net cycle number currently in effect. Each transmitting station is given a transmit position within the net cycle and transmission length assignments by the NCS. The assignments are based on requests from the individual stations during the last net cycle and the priority of those stations (only if some stations are prioritized relative to other stations). The lengths of the assignments are restricted by the maximum slot length (for one station) and the maximum cycle length, both of which are set in the NCS software. The NCS will reduce a station's transmit

opportunities to less than once per cycle, if the station consistently indicates that it has no data to transmit. The station opportunities will not be reduced to less than once per four net cycles, so that it will have the chance to make a request if data become available.

Each net member will transmit its TU at the conclusion of its predecessor's transmission (its predecessor is determined from the SOL). The true length of the predecessor's transmission is available from the beginning of the TU (not from the SOL).

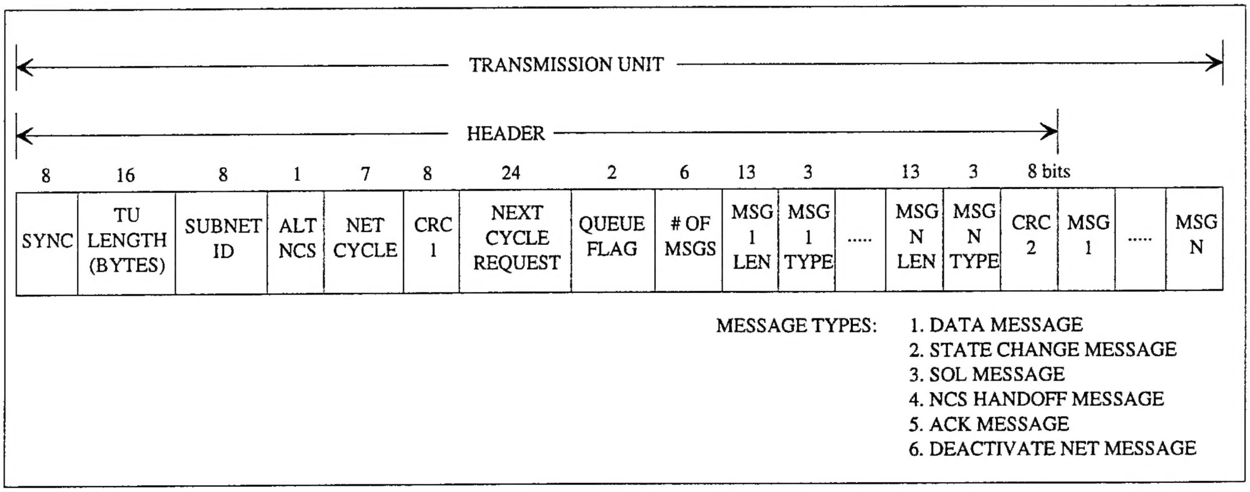

Figure 6. Transmission Unit Format

An error in either CRC 1 or CRC 2 upon receipt will cause the receiving SNAC to drop the entire TU. Each message following the header fields is made up of the message itself and an 8-bit CRC. The receiving SNAC drops any messages for which the CRC indicates an error.

A transmit queuing capability is maintained by the SNAC. The data sent by the IS is queued on a first-in/first-out (FIFO) basis except for the highest precedence level data. The data with highest precedence level is transmitted ahead of other data.

Received data is examined and routed to the destination IS. Any data within the received TU that is not directed to the local IS is discarded.

3.2 Software Implementation

The UHF SNAC consists of one Computer Software Configuration Item (CSCI) and the CSCI is composed of seven Computer Software Components (CSC): SNAC Manager (SM) , Net Control (NC), Transmit Queuing (XQ), Link Driver (LD), Interprocess Communications (IC), Time Keeping (TK), Statistics Maintenance (ST). The SM CSC is the first CSC to start and it subsequently initializes the other CSCs. It also fields input messages and PDUs from the ISs and routes them to the appropriate CSC. The XQ CSC maintains prioritized FIFO queues that holds the outgoing PDUs. It builds a TU composed of PDUs when called upon by the NC CSC. The NC CSC performs network control by managing access to the UHF SATCOM link. The NC CSC implements the reservation protocol. If the SNAC is the Net Control Site (NCS), the NC CSC performs the NCS functions of creating a SOL and assigning time slots for the other net members. The ST CSC maintains the statistics required by the ISs and called out in the SNAC Interface Document [3]. The IC CSC established the communications between the SNAC and ISs. The TK CSC maintains a record of the SNAC time and initiates time driven functions. Finally, the LD CSC provides

the interface between the SNAC and the I/O controller on the MVME333 serial I/O board. All the software is written in C using the VxWorks development environment.

3.3 Hardware Implementation

The CSCI is executed on a VME card, the Heurikon HK68V4F processor card. The HK68V4F interfaces to the IS via Ethernet. The output from the Heurikon card is the TUs. This data is sent to the Motorola I/O card which provides the interface to the WSC-3 radio. The I/O card output interface is RS232. The WSC-3 requires an MIL188-114 interface. So a RS232 to MIL188-114 converter is used to interface the I/O card to the WSC-3 radio. A block diagram of the hardware is shown in figure 7.

The radios operate in half duplex mode. The WSC-3 only has one synthesizer and therefore can not transmit and receive at the same time. It would have been preferred to operate in full duplex. However, that would have required two WSC-3 radios per node. The UHF SATCOM subgroup decided to use half duplex because some the participating organization did not have enough radios to operate full duplex. Full duplex operation would have eliminated part of the guard band between TU transmissions. The guard band between TUs is 0.58 seconds and is required because of path delay (0.28 seconds) and header delay (0.30 seconds). Full duplex operation would have eliminated path delay and resulted in a guard band of 0.30 seconds.

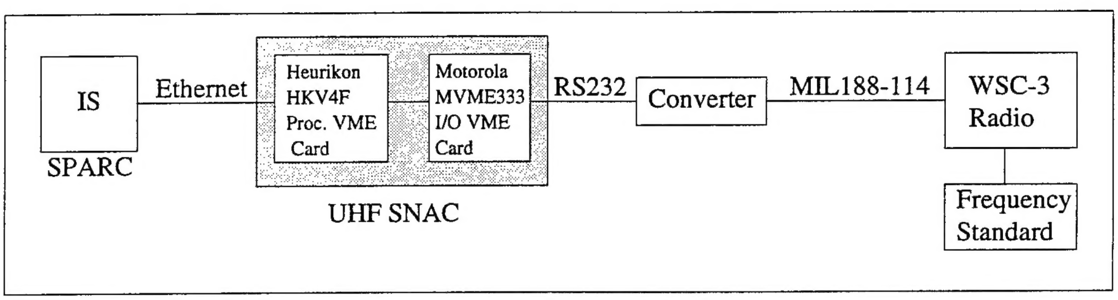

Figure 7, UHF SATCOM Hardware Configuration

3.4 Test Results

The data from four tests runs is shown in table 3. The network consisted of only two nodes of which one is the Net Control Station (NCS). Four different PDU sizes were tested. There are two point that should be noted. (1) Even though data were occasionally retransmitted, data were never lost. (2) As the amount of data increases per time period, the average delay also increases. This is expected because the TUs are becoming larger since there is more data per second to transmit. It is also interesting to note that the average delay of the NCS is about half of the delay for a regular node. This is also expected because the NCS does not have to wait a net cycle to request channel allocation. The other nodes have to request channel allocation in one cycle and then receive their allocation in the next net cycle.

Test No.	Node	Bytes/PDU per sec. per node	Bytes Transmitted	Bytes Retransmitted	Bytes Dropped	Ave. Delay (milliseconds)
1	1 (NCS)	100	10400	700	0	1973
	2	100	12500	400	0	3035
2	1 (NCS)	220	22220	5500	0	3271
	2	220	22220	7260	0	6619
3	1 (NCS)	325	31525	2600	0	3562
	2	325	34775	2600	0	6432
4	1 (NCS)	625	63750	0	0	11256
	2	625	60000	0	0	21695

Table 3. Summary of UHF SATCOM Test Results

3.5 Lessons Learned

One of the early design decision made by the UHF SATCOM subgroup was to use the internal modulator of the WSC-3 radio rather then an external modem. One of the early lessons learned was that the internal modulator is a very poor modulator. The modulator required a large period to synchronise which resulted in larger guard band. Also the modulator was very susceptible to noise which caused TUs to be lost, resulting in the SNAC retransmitting the TU. It was also discovered that the radio had excessive frequency draft. This was solved by connecting the radio to an external frequency standard.

4.0 CONCLUSIONS & RECOMMENDATIONS

Two SATCOM networks were successfully developed for CSNI: SHF and UHF. Both networks were successfully tested over the air. The DSCS and NATO SHF SATCOM subnetworks provide the CSNI program with two high capacity data links (a data rate, excluding protocol overheads of 41.5 and 53.6 Kbps respectively). The two SHF subnetworks are reliable (during the basic performance tests, see 2.4, no data was lost).

If the two SHF SATCOM subnetworks are to be used in a true military environment then further development work is required on both DSCS and NATO subnets. There are several possible enhancements that could be made to the SHF SATCOM subnetworks to improve the throughput, the joining/leaving processes (DSCS only) and the token passing algorithm (DSCS only). Some of these enhancements were detailed in 2.5.

The UHF SATCOM subnetwork provides CSNI with a low data rate SATCOM subnetwork. Since most military channels are low data channels, the UHF SATCOM subnetwork provided CSNI with a channel to test OSI protocols over low data rate SATCOM links.

The UHF SATCOM subnetwork proved to be a reliable network. However, further improvements can be made to the subnetwork design, particularly to the hardware. Operating full duplex would decrease part of the delay in the network and decrease the net cycle time. The use of a better modem would increase the reliability of the network and decrease retransmissions. This would also decrease delay.

5.0 REFERENCES

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